Status of the High Current Proton Accelerator for the TRASCO Program

Paolo Pierini
INFN Milano - LASA
on behalf of the TRASCO_ACC group

TRASCO_ACC
D. Barni[a], G. Bellomo[a], G. Bisoffi[b], A. Bosotti[a], L. Celona[c], A. Chincarini[d], G. Ciavola[c], M. Comunian[b], A. Facco[b], S. Gammino[c], G. Gemme[d], G. Lamanna[e], A. Lombardi[b], P. Michelato[a], M. Napolitano[f], C. Pagani[a], A. Palmieri[b], R. Parodi[d], P. Pierini[a], A. Pisent[b], F. Scarpa[b], D. Sertore[a], V. Zviagintsev[b],

[a]INFN Milano LASA http://wwwlasa.infn.it
[b]INFN-LNL http://www.lnl.infn.it
[c]INFN-LNS http://www.lns.infn.it
[d]INFN Genova http://www.ge.infn.it
[e]INFN Bari http://www.ba.infn.it
[f]University and INFN, Napoli http://www.na.infn.it

The TRASCO Program

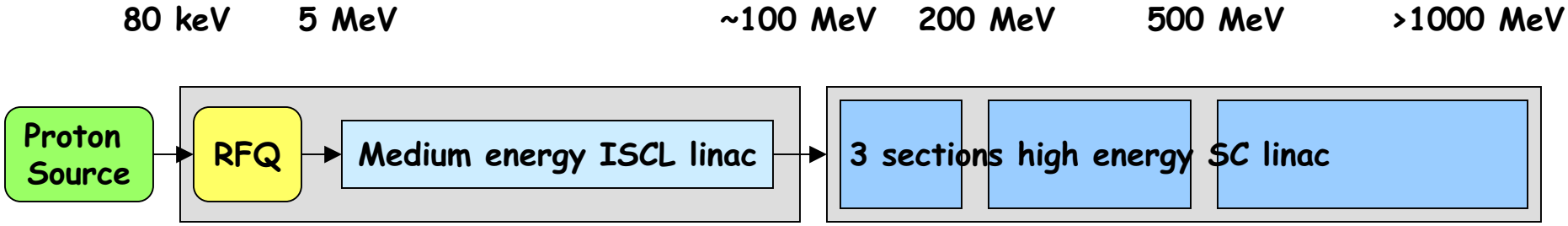
TRASCO: **conceptual study** and the **prototyping of components** for an **accelerator driven system for nuclear waste transmutation**, and involves research agencies and Italian companies

- TRASCO/ACC
  - **Accelerator studies**: lead by INFN
- TRASCO/SS
  - **Subcritical reactor** studies: lead by ENEA

TRASCO/ACC (1998-2004, in three funding stages) is devoted to:

- Conceptual design of a high current superconducting proton linac
  - **I=30 mA, E = 1 GeV**
- Construction and R&D activities on key items:
  - an 80 kV, 35 mA proton source **(INFN - LNS)**
  - a 5 MeV, 30 mA, CW RFQ **(INFN - LNL)**
  - SC cavity prototypes for low β cavities (<100 MeV) **(INFN - LNL)**
  - SC cavity prototypes for β = 0.47 elliptical cavities **(INFN - MI)**
  - SC cavity prototypes for β = 0.85 sputtered cavities **(INFN - GE)**
  - engineering of elliptical SC linac components (cryomodules, etc.) **(INFN - MI)**

The Reference Linac Design



Source	RFQ	ISCL	High Energy SC Linac
Microwave RF Source High current (35 mA) 80 keV	High transmission 95% 30 mA, 5 MeV (352 MHz)	5 - 85/100 MeV SC linac Baseline design: Reentrant cavities (352 MHz) Alternative design: Spoke, λ/2, λ/4, ladder 8βλ FODO focussing with sc magnets	3 section linac: - 85/100 - 200 MeV, β=0.47 - 200 - 500 MeV, β=0.65 - 500 – 1000/2000 MeV, β=0.85 Five(six) cell elliptical cavities Quadrupole doublet focussing: multi-cavity cryostats between doublets - 704.4 MHz

TRIPS: TRASCO Intense Proton Source

High intensity (tens mA) proton sources exist, but ADS asks for high reliability and availability

Additional efforts are required for:

- Voltage and current stability
- Control of the low beam emittance

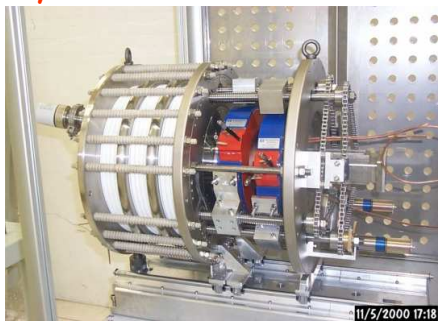
Design in 1999, source in LNS in May 2000

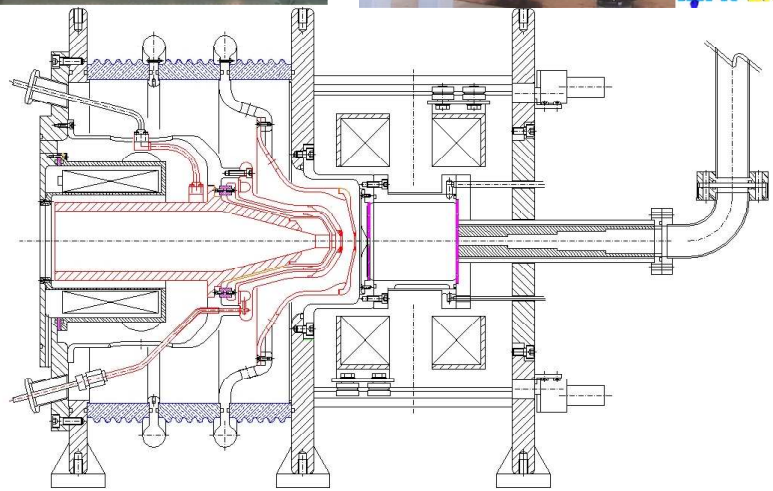
Achievements:

- First beam of 20 mA @ 60 kV in Jan 2001
- 80 kV, 55 mA operation in Aug 2001

Off-resonance microwave discharge source (2.45 GHz), based on SILHI (CEA/Saclay)

- Pentode configuration with new geometry
- Lowered voltage: from 95 kV to 80 kV





TRIPS Goals:		Achieved
Proton Beam current	35 mA	55 mA (~90% p.f.)
Beam emittance	0.2 π mm mrad	To be measured
Operating voltage	80 kV	80 kV

TRIPS recent performances

A rms emittance below 0.2 π mm mrad has been calculated with beam dynamics simulations, crosschecking different codes

- Emittance unit from CEA is being shipped to Catania for measurements

LEBT for beam analysis and characterization:

- Solenoid (focussing)
- Beam alignment monitor
- 2 current transformers for beam current measurements
- 10 kW beam stop

Reliability tests have been performed:

- **at 65 kV/15 mA: 24 h with no beam interruptions**
- **Tests at 80 kV are underway (improving)**

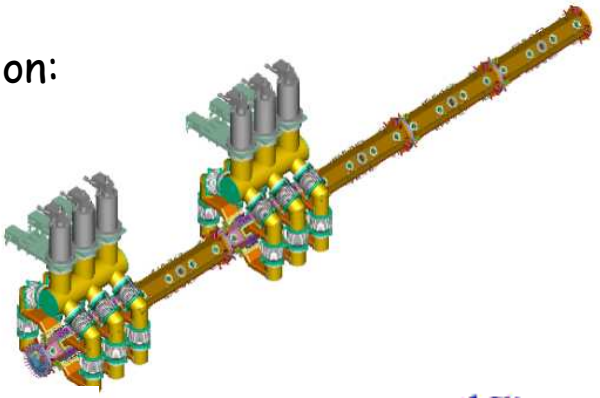
A new control system for automatic restart procedures after discharge is being implemented

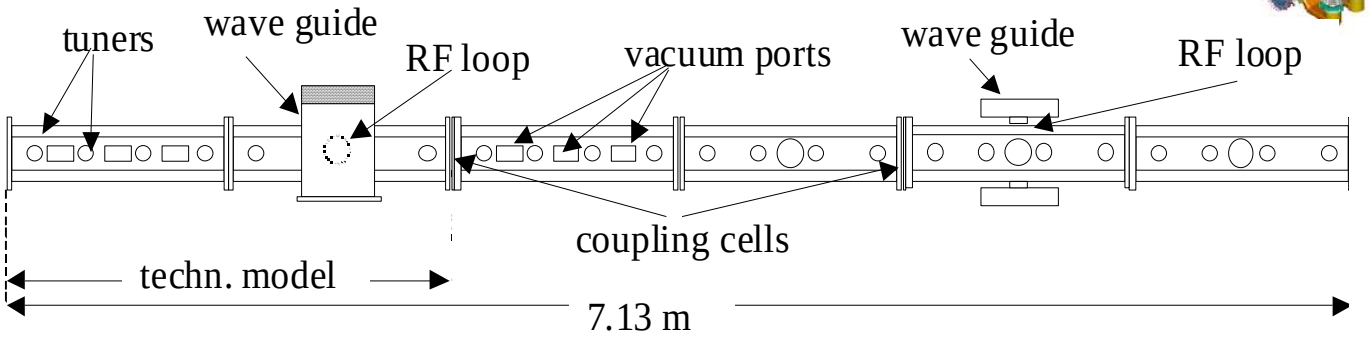
Low Energy Linac

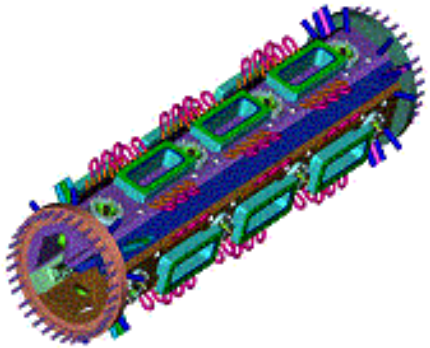
Laboratori Nazionali di Legnaro

The low energy linac is split in two components:

- A normal conducting CW Radio Frequency Quadrupole (RFQ): from 80 keV to 5 MeV
  - RFQ design: 3 resonantly coupled segments. Modulation:
    - Radial match in the structure
    - Shaper
    - Gentle buncher (from dc to 352.2 MHz bunches)
    - Accelerator (boosts up to 5 MeV, longest portion)







- A superconducting linac (ISCL): from 5 MeV to 100 MeV
  - Reentrant cavities for highest availability (allowing beam on with 1 cavity off)
  - $\lambda/4$, $\lambda/2$ cavities
  - Spoke cavities

RFQ Design and Fabrication tests

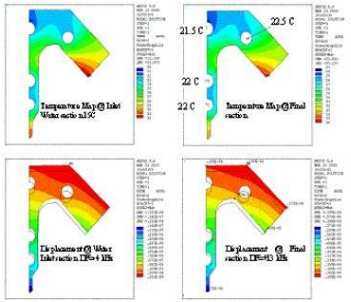
Different optimization procedure for TRASCO RFQ w.r.t. LEDA

- Limit to 1 RF source (1.3 MW CERN-LEP klystron)
- Lower current of 30 mA (96 % transmission)
- Peak surface electric field is 33 MV/m, (1.8 Kp)
- Simplified engineering/manufacturing choices

Substantial heat dissipation in the structure ~ 600 kW total

Three resonantly coupled segments

TRASCO RFQ:	
Beam current	30 mA (96 % transmission)
Beam emittance	0.2 π mm mrad T
	0.18 π deg MeV L
Final Energy	5 MeV
Length	7.13 m (3 sections)
RF Power	150 kW (beam)
	600 kW (structure)
Peak Field	1.8 Kilpatrick

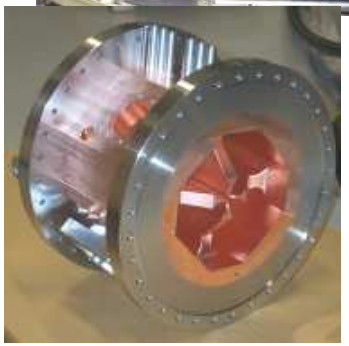


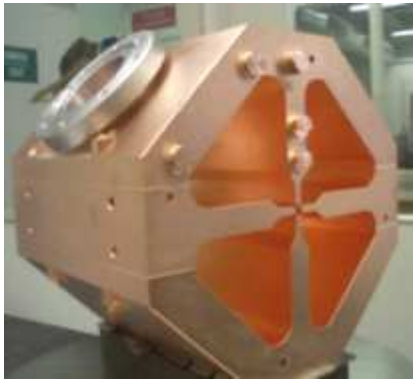
A 3 m Al model of the structure has been built and measured at LNL, and achieved the necessary field stabilization

A 220 mm part of the structure has been built to test the full fabrication procedures

- Brazing
- Water channels by long (1 m) drilling

Full structure is under fabrication





Superconducting low energy linac

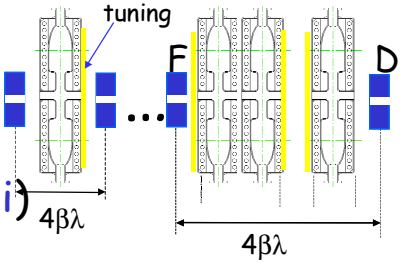
Laboratori Nazionali di Legnaro

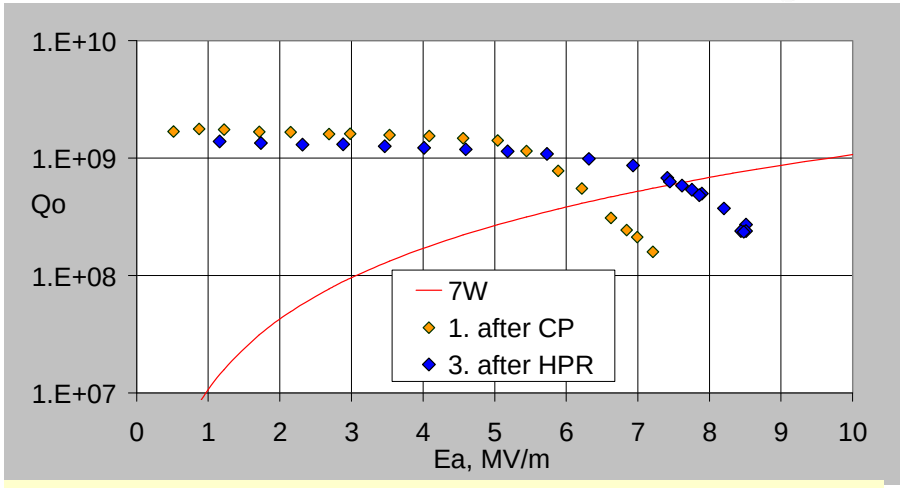
Single or two-gap structure linac

- Moderate energy gain/cavity
- Solid state RF amplifiers
- 8 βλ focussing lattice

Various options, are being considered

- Reentrant cavities
- Spoke cavities
- λ/4 cavities
- Ladder (see G. Bisoffi)

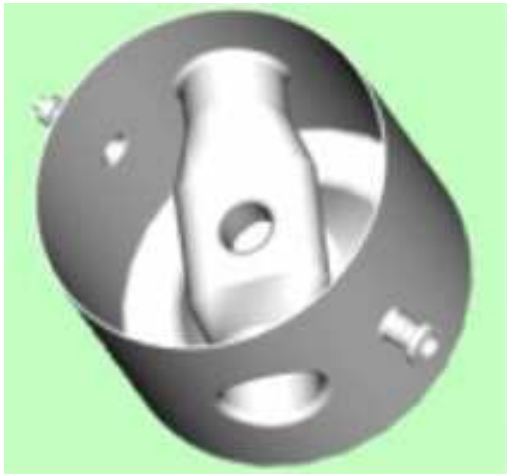




See A. Facco talk (13:40 October 8)

Quarter Wave resonator (QWR) 2 gap structure of the ALPI linac in INFN-LNL

2 gap spoke cavity



Reentrant cavity single gap structure.
He Vessel integrated in the cavity

The high energy linac

Conceptual design of the 3 section linac

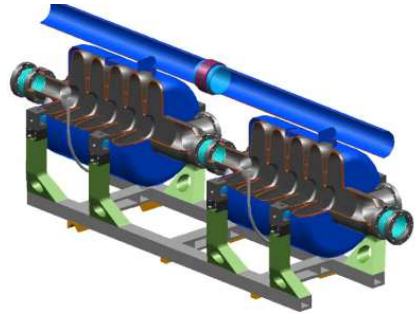
Development and test of prototype cavities

- At 352 MHz with the LEP II sputtering technology
- At 704 MHz, bulk niobium, for the lowest β

Design and engineering of cavity components and ancillaries

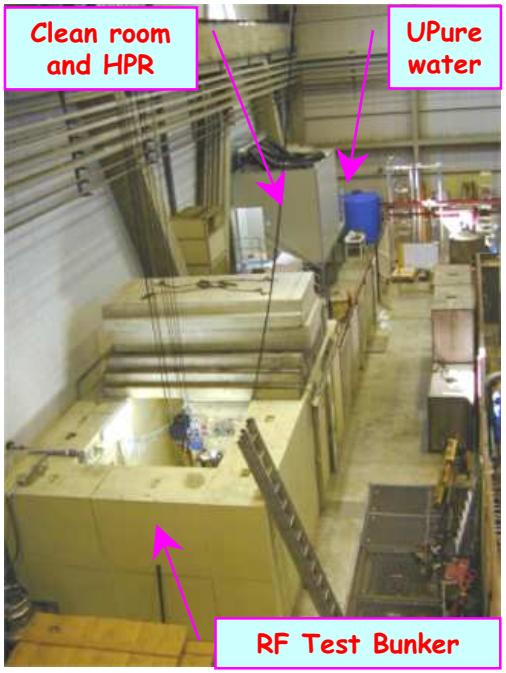
- Cryomodule, tuner system, piezo damping, …

RF Test infrastructure



Designed with high current beam dynamics criteria to avoid emittance growth (smooth, tune resonances, ...)

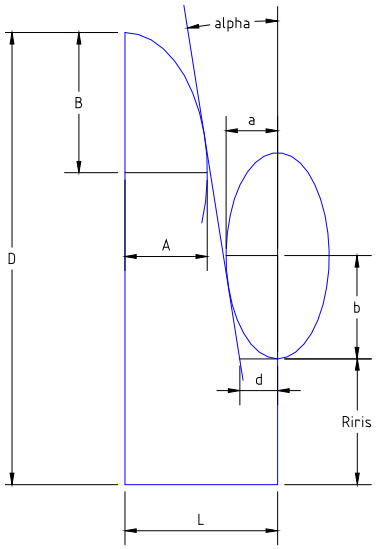
Section β	0.47	0.65	0.85
# cells/cavity	5	5	6
Length	50 m	93 m	102 m
Initial/Final Energy	100 MeV	190 MeV	480 MeV
	190 MeV	480 MeV	1 GeV
Doublet period	4.2 m	5.8 m	8.5 m
# periods	12	16	12
# cavities in section	24	48	48
Max. Eacc (MV/m)	8.5 MV/m	10.2 MV/m	12.3 MV/m

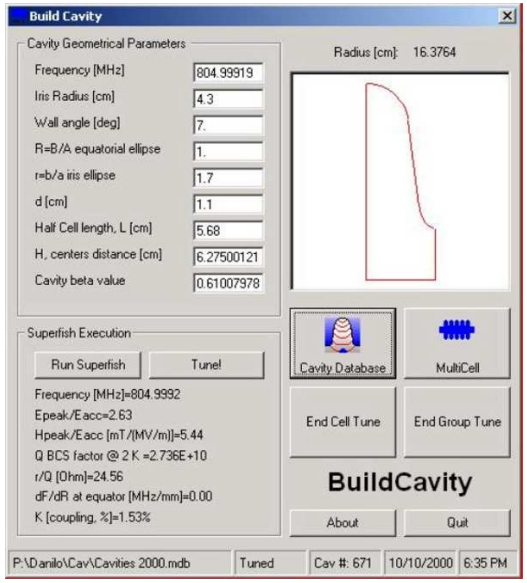


Conceptual design: cavity & linac design

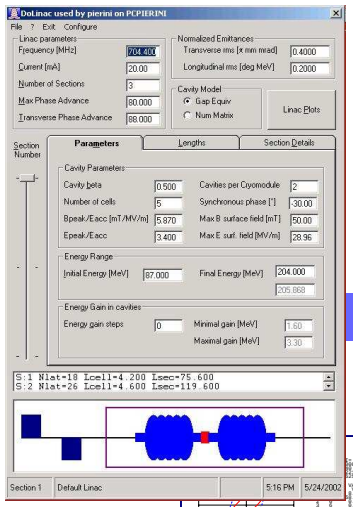
INFN Milano LASA

- Parametric tool for the analysis of the cavity shape on the electromagnetic (and mechanical) parameters
- Inner cell tuning is performed through the diameter, all the characteristic cell parameters stay constant: R, r, α, d, L, Riris
- End cell tuning is performed through the wall angle inclination, α, or distance, **d**. R, L and Riris are set independently
- End groups for a 4 die cavity tuned using the end cell diameter (and α,d,R,L, Riris are indep. set)



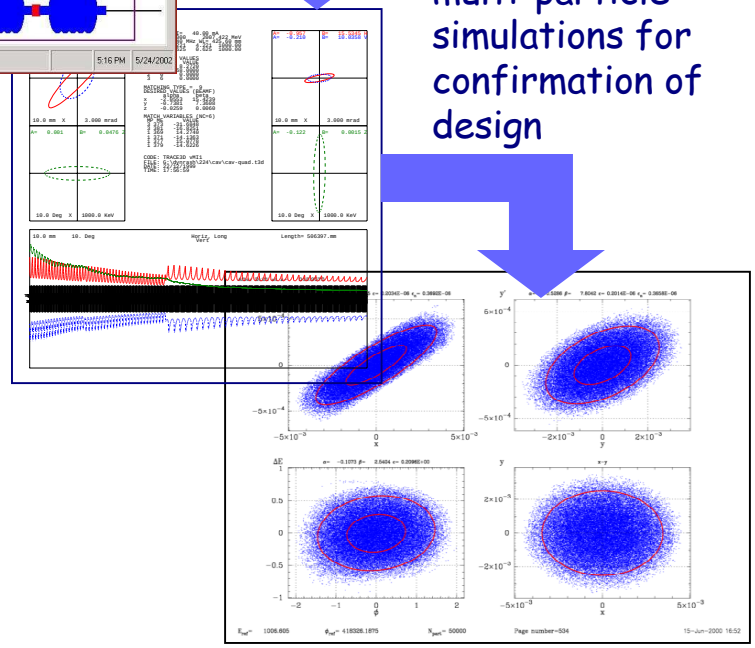


Build linac from **simple rules**, with **control of longitudinal & transverse phase advances**



Find **matched beam** solution in all linac

Run non-linear multi-particle simulations for confirmation of design



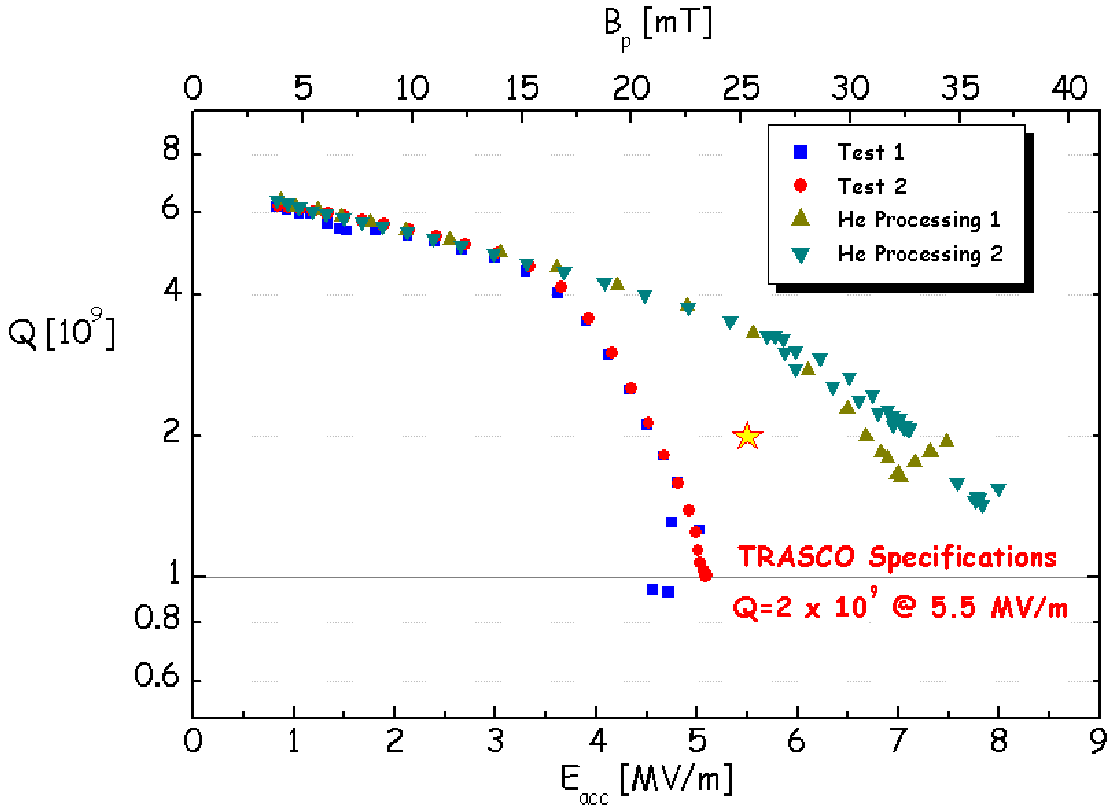
352 MHz β=0.85 prototypes with CERN

352 MHz cavities with CERN (MOU)

- Use LEP II sputtering technology
- Single cell and 5 cell sputtered - β = 0.85
- Cavity integrated in a LEP type cryostat

All tests reached the design goals, indeed performed as the best LEP batch

But: Bulk niobium is needed at lower β, and the gradient is moderate w.r.t 704 MHz



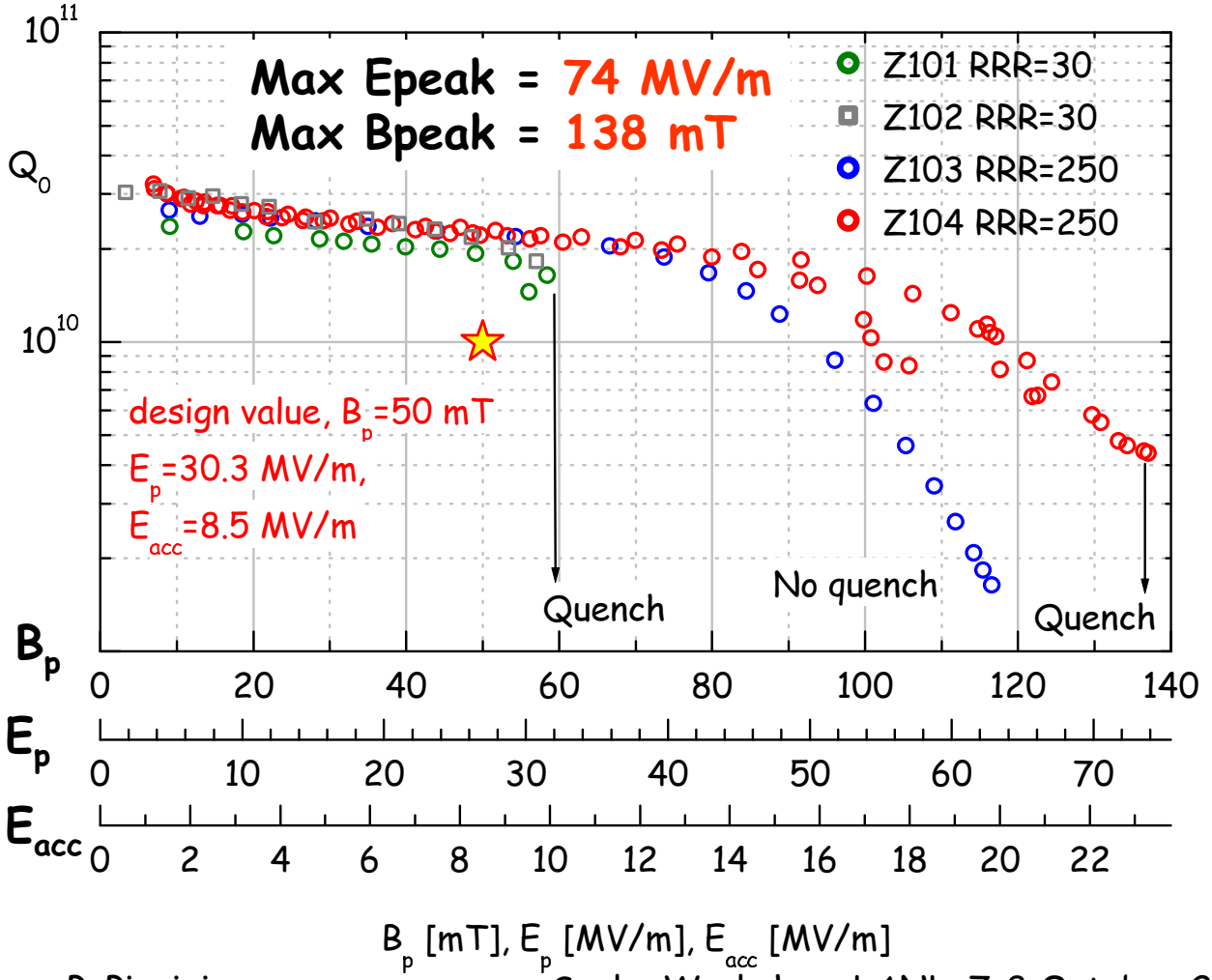
Test in a modified LEPII cryomodule (Aug. 2001)

- Powered to 250 kW
- 7 MV/m

β=0.47 single cell cavities prototypes

Fabricated with RRR>30 & RRR>250 Niobium at Zanon

BCP, HPR and tests at TJNAF (Z104) and Saclay (Z101-Z103)



For 1-cell:

E_p/E_{acc} = 2.90

B_p/E_{acc} = 5.38 mT/(MV/m)

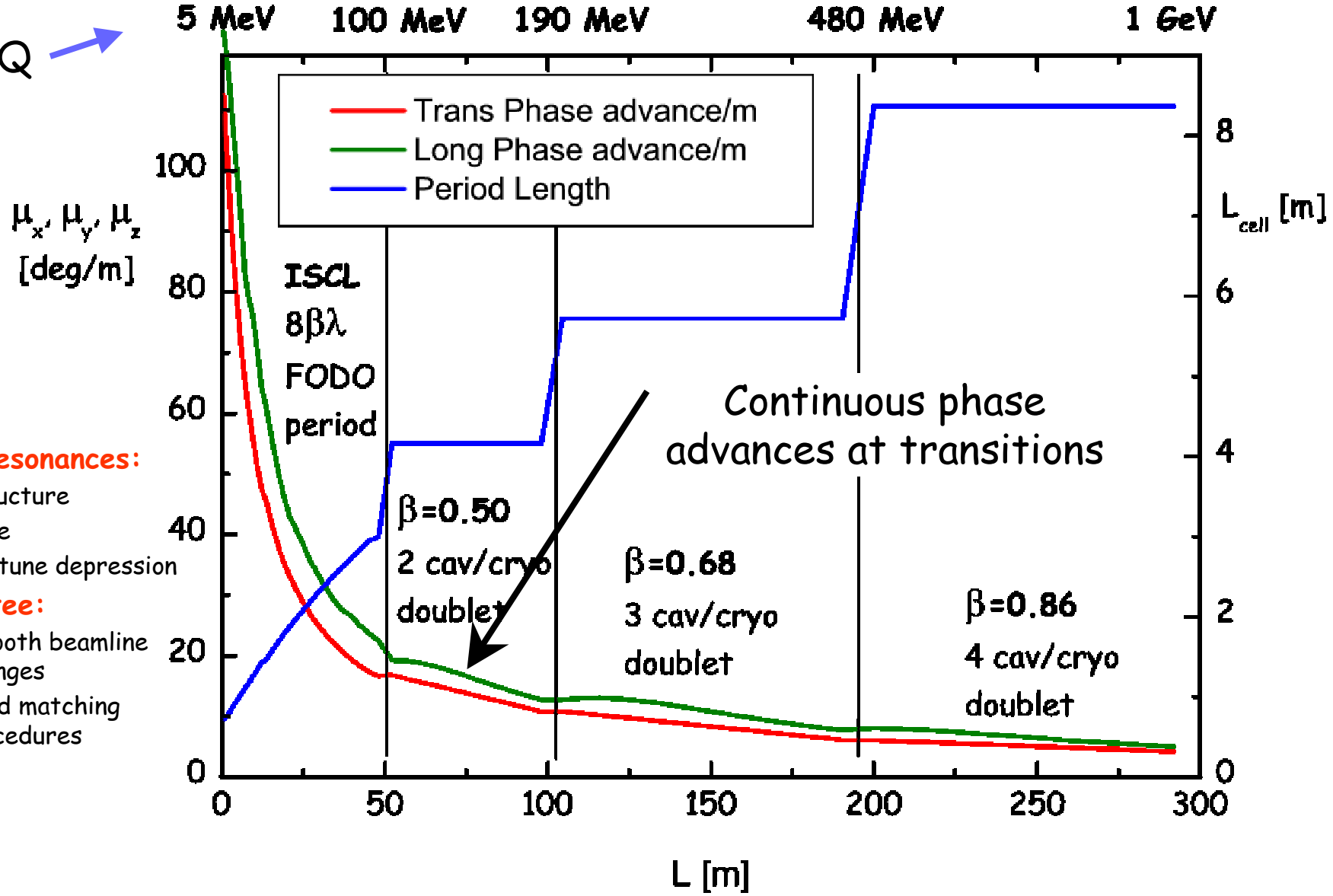
For 5-cell:

E_p/E_{acc} = 3.57

B_p/E_{acc} = 5.88 mT/(MV/m)

Two 5 cell cavities are under fabrication at ZANON

Baseline of the "smooth" linac design



Avoid resonances:

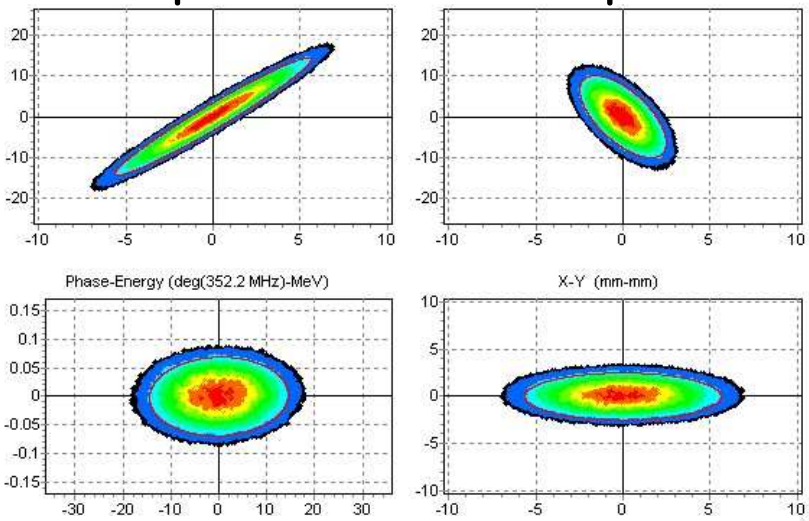
- Structure
- Tune
- Big tune depression

Guarantee:

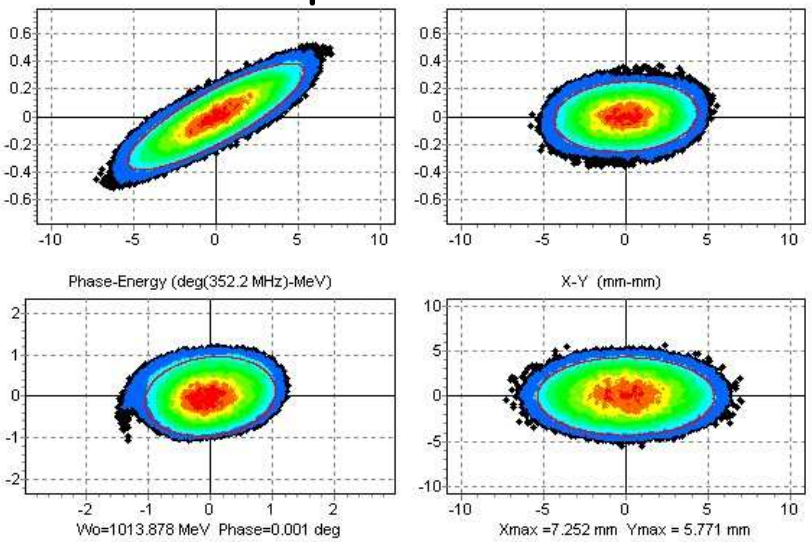
- Smooth beamline changes
- Good matching procedures

Full SC linac from 5 MeV to 1 GeV

Input @ 5 MeV 10^5 ptcl

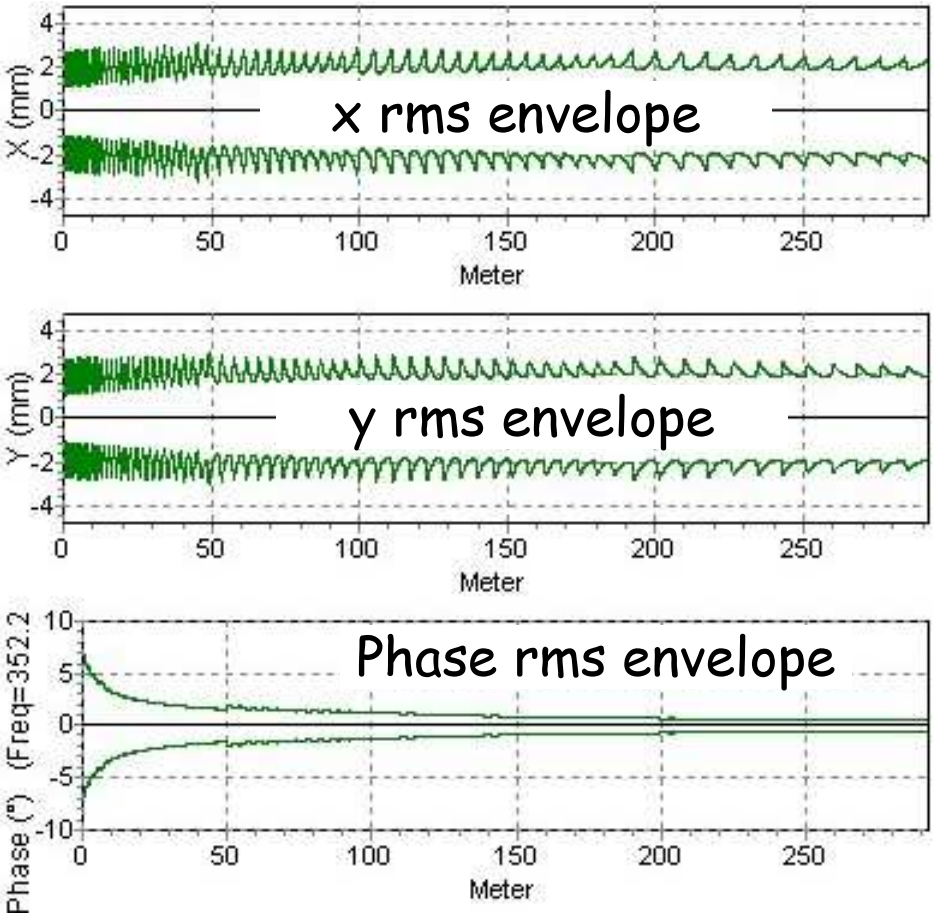


Output @ 1 GeV

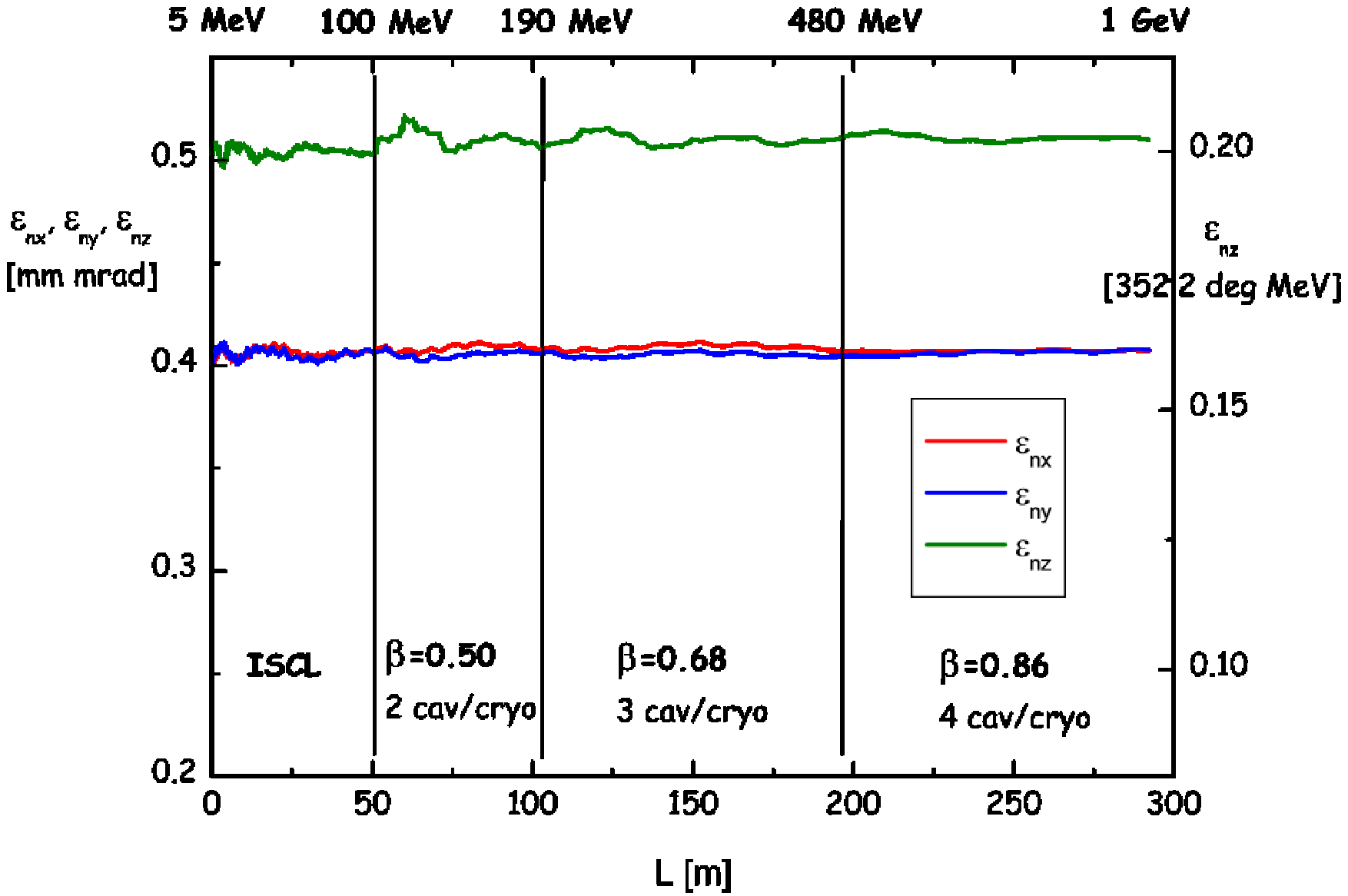


Results of non-linear simulations

No particle losses, beams well confined



Rms emittances growth (from end of RFQ to full energy) < 2%



Perspectives

The effort to build a complete ADS system exceeds the capabilities (and the funding availability) of any national program like TRASCO

- TRASCO means to provide significant R&D and prototipical effort along the road to the design of a transmuter system
- cfr. "*A European Roadmap for Developing Accelerator Driven Systems (ADS) for Nuclear Waste Incineration*", by the European Technical Working Group on ADS, April 2001 (available in http://itumagill.fzk.de/ADS/)

Already in the 5th Framework Program of the European Commission a Program has been funded: "**PDS-XADS** – Preliminary **D**esign **S**tudies for an e**X**perimental **A**ccelerator **D**riven **S**ystem"

- 25 Partners, from Research Institutions to EU Industries
- 12 M€ Program (50% supported by the Commission)
- Several Working Packages, dealing with various aspects of an ADS
- WP3 is dedicated to the Accelerator

More to come in the 6th Framework Program about to start …